

# The Influence of Average Annual Climatic Indicators on Agricultural Productivity: Considering the Threshold Effect

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## Summary

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The article examines the effects of average annual temperatures, the average annual amount of precipitation and carbon emissions per capita on changes in the overall indicator of productivity in agriculture. The volume produced per one ha of agricultural land in real (physical) terms based on the data for six decades is considered. Econometric analyses show that there is a threshold effect in the impact of the average annual temperature and the average annual precipitation on changes in agricultural productivity. Findings demonstrate that the changes in quantitative indicators for average temperature and precipitation up to a certain point and changes in agricultural productivity stemming from these factors occur in the same direction. In this case, the scale of the observed influence increases with the increase in climate indicators. After each of the specified factors reaches a certain critical level, changes in them and in the level of the agricultural productivity move in opposite directions. Thus, the scale of the effect on productivity grows according to the increase of both climate indicators; however, the average indicators of temperature and precipitation have a negative effect on productivity after a certain critical threshold, and the magnitude of the negative effect increases in accordance with the increase of the climatic indicators. Critical values have been calculated for these climatic factors, the excess of which will lead to a slowdown in growth and a decrease in the overall productivity in agriculture.

## Key words

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Climate changes, average climate indicators, agriculture, agricultural productivity, drought

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## Introduction

Having considerable impact on the global climate change, agricultural sector stands as one of the important areas of economy. Hence, this aspect is more pronounced in developing countries, where the dependence of agricultural production results on climatic factors is relatively high. Indeed, the impact of climate change on the agricultural sector is multifaceted.

In this regard, the primary questions to be addressed are the ones about the productivity levels which might be affected due to the changed production conditions of some plants. These changes involve the total shifting of the heat and humidity range, as well as of the raised heat stress among the farm animals. Consequently, interesting research was carried out on the influence of climatic factors on the yield of certain plant species, including the yield of grain (Amponsah et al. 2015; Laxmi & Kumar, 2011; Heinzow & Tol, 2003; Holzman et al. 2014; Tulbure et al. 2012; Huang et al. 2015; Lobell & Burke, 2010; Tao et al. 2009; Almaraz et al. 2008; Erda et al. 2005; Amponsah et al. 2015), rice (Aggarwal et al. 2010; Auffhammer et al. 2011; Farook & Kannan, 2016), olives (Zaied & Zouabi, 2015).

Additionally, in terms of broadening assurances for the implementation of effective strategies for adapting to and mitigating climate change, there is a need for detailed clarification regarding the impact of climate factors on the overall development indicators of the field. In this direction, the inclusion of data covering a longer period of time in the research area can open opportunities for a detailed explanation of the impact of climate changes on the general dynamics of production in the agrarian field and for revealing the main aspects in this field. Within the framework of such an approach to the issue, it becomes possible to test the hypothesis that the effect of the change of climate indicators on productivity in agricultural production is not unambiguously negative or positive in all cases.

Based on data from 1961-2021, the article intends to examine the effect of average annual temperature, average annual precipitation and per capita carbon emission indicators on the overall productivity index in agricultural production in Azerbaijan - to the change in the physical volume of agricultural output per ha of agricultural land. As a result of the research, it is determined that there is a threshold effect in the effects of average annual temperatures and the average annual amount of precipitation on the change of the general productivity indicator of agricultural production, and based on this, appropriate evaluations are made.

The structure of the paper is as follows: The current section introduces the background of the topic and the ensuing section is a review of the related literature. The third section describes the research methodologies. In the fourth section, we provide the results of our analysis and discuss the findings. We summarize our research in the fifth section.

## Literature Review

In the literature on the effect of climate factors on general development indicators in agriculture, including the productivity in agricultural production, the issue is considered by individual authors on the basis of data from different periods and on the basis of different models. At the same time, different indicators of productivity are used.

In the studies, the influence of climatic factors on the general indicators of the development of agricultural production was considered separately or together with other factors. In the first direction, Dumrul and Kılıcarşlan (2017) analyzed the effect of temperature and precipitation factors on the added value created in agriculture in Turkey according to the ARDL model based on the data of 1961-2013 and showed that the increase in precipitation had a positive effect on the development of the agricultural area, and the increase in temperature had a negative effect.

Another study in the direction we mentioned was conducted by Bayrac and Dogan (2016) based on the ARDL approach; the authors examined the impact of climate changes on the added value created in agriculture in Turkey on the basis of the ARDL approach, taking the specific weight of the added value created in the field (agricultural GDP) as an indicator of agricultural productivity, and so came to the conclusion that the amount of precipitation had a positive effect on productivity in agriculture, and the level of carbon emission and temperature had a negative effect (Bayrac & Doğan, 2016).

Brown et al. (2010), in their research carried out on the basis of the data of 1961-2003 for 133 countries on the impact of climate changes on growth at the national level, concluded that the increase in the amount of rain had a positive effect on the share of agriculture in the GDP, and the increase in air temperatures had a negative effect.

Akalin (2014), based on the data of 1972-2009, in his research on Asian countries, showed that precipitation had a positive effect on the share of agriculture in the GDP, and the increase in temperature had a negative effect.

Based on the analysis of panel data of 1990-2016 for 10 countries, Hayaloglu (2018) came to the conclusion that the aforementioned changes had a negative impact on economic growth and agricultural added value.

In the research of Bashoglu and Telatar (2013), as a result of the regression analysis conducted with annual data for the years 1973-2011, it was determined that the agricultural sector was negatively affected by temperature changes, and positively by precipitation changes. However, since the coefficient of temperature variability is greater than the variable coefficient of precipitation, it was concluded that the overall impact of climate change on the agricultural sector was negative.

According to the second direction mentioned earlier, Mubenga-Tshitaka et al. (2023), based on the data of 1961-2016 for temperature and precipitation indicators in East African countries, together with other factors affecting the development of agriculture, such as the number of workers, fertilizer consumption, provision of equipment, land areas, the long-term effects of temperature variability on agricultural production and precipitation variability, observed that climatic factors had a short-term effect. However, after accounting for heterogeneity across countries, the evidence for long-term effects of precipitation variability was found in some countries.

Some of the studies focus on the impact of carbon emissions on the overall results of agricultural production. In this direction, Rehman et al. (2019), in their studies of the relationship between CO emissions and productivity in Pakistan's agriculture with

the Autoregressive Distributed Lag Bounds Testing Approach, concluded that the increase of this indicator had a negative effect on the production of food wheat and the improvement of the distribution of seeds.

Alam's (2013) study of the impact of climate change on agricultural productivity and economic growth based on the ARDL model made on the data of India from 1971 to 2011 concluded that there was a positive relationship between agricultural productivity and economic growth, and a negative relationship between CO<sub>2</sub> emissions and economic growth.

Chandio et al. (2020), in the study on Pakistan based on the ARDL approach founded on the data of 1983-2016, showed that CO<sub>2</sub> emission had a positive effect on the results of production in agriculture, but the corresponding indicator did not receive a statistically significant value.

A study by Deschênes and Greenstone (2007) assessed the impact of annual variations in temperature and precipitation on agricultural profits and showed that climate change would lead to an increase in annual profits. Recently, some papers have focused on the effects of climate change on agriculture in Azerbaijan. Huseyn (2011), Nesiroy (2021), Musayev (2023) and others discussed the negative effects of climate change on agriculture in Azerbaijan. Musayev's (2023) research, dedicated to the assessment of the impact of economic and climate factors on agricultural added value with the ARDL model based on the data of 1995-2020 showing that the effect of temperature rise on the amount of added value was negative. However, this paper for the first time examines the impact of annual average climate indicators on agricultural productivity in Azerbaijan.

## Data and Methodology

### Data

The research is conducted on the basis of data covering the years 1960-2021. It should be noted that in the former USSR, which also included Azerbaijan, the official statistics did not calculate the added value indicator. In this regard, there are no data for the years 1960-1990 on the indicators of the added value in general and in each field. Taking this into account, we have evaluated the overall productivity indicator in agricultural production with the physical (real) volume indicator of agricultural products that can be calculated for the entire studied period. The physical volume of the total product by years was calculated in 2005 Azerbaijani manat (AZN). The indicators of national statistics on the area of agricultural lands included in the study were also taken.

Average annual temperature, average annual precipitation and information on carbon emissions per capita were mainly taken from the relevant data base of the World Bank. At the same time, the information provided in the internet resources of "OurWorldinData" (for 1960-1970) and Worldometer (2024) were also used. The indicator of carbon emissions per capita for 1970, as well as the quantity of the mentioned indicator for 1992, were taken from the Worldometer. We believe that the last information more correctly expresses the amount of carbon emissions in Azerbaijan in 1992, taking into account the factor of the change of the main factors affecting this indicator in that year. The mentioned information is given in Appendix one and two.

### Method

The relationship between the indicator of the general level of productivity in agriculture - the physical volume of agricultural products in relation to 1 ha of agricultural land and the dynamics of climate factors is investigated on the basis of econometric methods. In this case, a multi-step algorithm is used:

- **At the first stage**, the features in the long-term dynamics of the studied indicators are clarified based on visual examination of the corresponding time series.
- **At the second stage**, the stationarity of the time series is checked by appropriate tests.
- **At the third stage**, cointegration between non-stationary series is verified by appropriate tests.
- **At the fourth stage**, the interdependencies between climate indicators are studied and the identified dependencies are assessed.
- **The fifth stage**, examines the nature of the relationship between productivity and climate indicators. The discovered nonlinear dependencies are reduced to a linear form.
- **At the sixth stage**, an econometric model is built and the necessary calculations are made based on the database.
- **At the seventh stage**, appropriate estimates are made based on the regression coefficients of the model.

The stationarity of the time series variables for the data included in the study was conducted using the Stata program based on the Augmented Dickey-Fuller (ADF) criterion. The results of the corresponding tests are given in Table 1.

As the table makes it clear, the variables for average annual temperature indicators and average annual rainfall indicators are stationary, and the physical volume of agricultural output and agricultural output per ha of agricultural land, the area of agricultural land and carbon emissions per capita are non-stationary. At the same time, the series consisting of the first difference in the indicators of non-stationary variables are stationary.

Taking into account the above, the variables of the time series related to the physical amount of the agricultural product per ha of agricultural land and the amount of carbon emissions per person are included in the model at the level of the first differences.

As mentioned previously the variables in the series on the physical volume of agricultural product per ha of land, as well as the variables in the series on the amount of carbon emissions per capita were entered into the model at the level of first differences, and the data on the average annual temperature and precipitation were entered into the model according to initial data. Going forward, the presence of cointegration between series whose variables are non-stationary in the initial case, as well as the relationships between productivity and climate indicators (linear or non-linear) will be checked.

Taking into account that the series included in the study are initially mixed in terms of stationarity, the presence of cointegration on non-stationary variables - AGOL - CEPC pair was checked by the Engel-Granger method. The stationarity of the residuals of the statistical regression between the series mentioned above was tested by the extended Dickey-Fuller (ADF) test. The results showed that the residuals were non-stationary (Table 2).

**Table 1.** Results of the Augmented Dickey-Fuller (ADF) test for stationarity of variables

Variables	Results of the test		Status
	Test statistic	Critical value	
Physical volume of agricultural output at 2005 prices, million AZN (AGO)	-0.061	-3.565*	Non -stationary
Agricultural lands, thsd. ha (AGL)	-1.135	-3.565*	Non -stationary
The physical volume of agricultural output per ha of AGL area, AZN (AGOL)	-0.324	-3.565*	Non -stationary
Annual average temperature, °C (AAT)	-4.606	-3.565*	Stationary
Annual average number of precipitation, mm (AAP)	-7.004	-3.566	Stationary
Carbon emission per capita, tonnes (CEPC)	-0.616	-3.565*	Non stationary
Δ AGL			Stationary
Δ AGOL	-7.004	-3.566*	Stationary
Δ CEPC	-5.900	-3.566*	Stationary

Note: \* critical value at  $P < 0.01$

Source: Author's calculations performed using the STATA 15 program based on application data

**Table 2.** Results of tests for detection of cointegration between non-stationary series

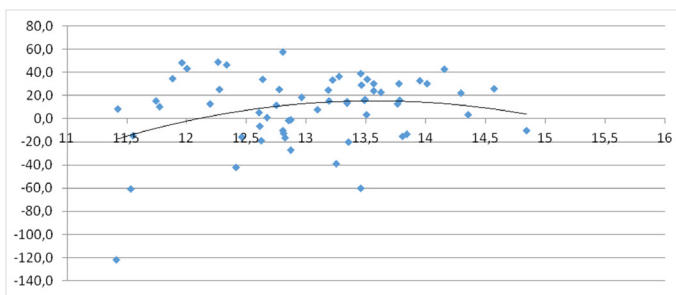
Variables	Darbin –Watson Coefficient		ADF test		F-statistic on ECM regression coefficient /P-value
	Aktual	d-statistic $d/d_u$	Aktual	Critical value/ P-valeur	
CEPC/ AGOL	0.09478	1407/1.468	0.088	-2.596/0.9653	0.7949/0.259525

Source: Author's calculations performed using the STATA 15 program based on application data

Accordingly, in the error correction model built on a pair of series, the corresponding regression coefficient did not exhibit a reliable value. Based on these tests, cointegration was not found between the studied non-stationary series.

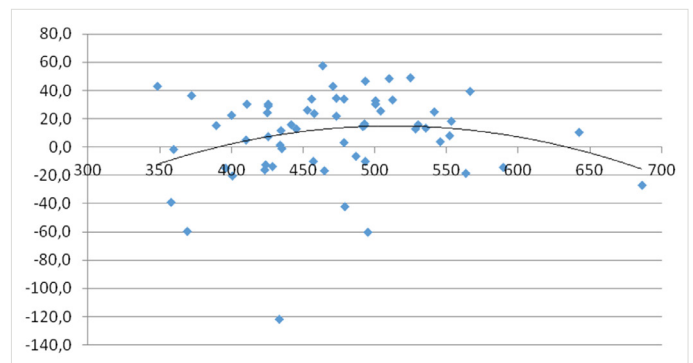
Considering the above, the ECM indicator was not included in the model showing the dependence of agricultural productivity on climate factors.

The characteristics of relationships between climate indicators and changes in agricultural productivity were evaluated based on the form of the relevant trends for each of the independent and dependent variables included in the model (Figs. 1-3).



**Figure 1.** Average annual temperatures and changes in agricultural productivity (Source: Author's calculations based on application data)

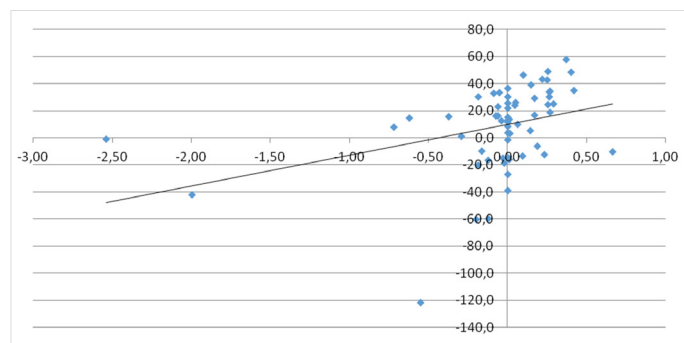
The figures show that the relationship between the average annual indicators of temperature and precipitation and the changes of productivity in agriculture were non-linear and corresponded to the polynomial function of the second degree.



**Figure 2.** Average annual precipitation and changes in agricultural productivity (Source: Author's calculations based on application data)

The relationship between carbon emissions per capita and productivity changes is linear, taking into account the relevant criteria. We brought the non-linear relationships into a linear form to include in the models. (Note that in the model used in

China for the factors for the formation of farm incomes, the data for temperature and precipitation were also brought into a linear form) (Mendelsohn, 2014).



**Figure 3.** Carbon emissions per capita and changes in agricultural productivity (Source: Author's calculations based on application data)

Utilizing the above, a polynomial coefficient linear model was constructed for the dependence of agricultural productivity on climate factors :

$$\Delta AGOL = \alpha_0 + \alpha_1 AAT + \alpha_2 AAT_2 + \alpha_3 AAP + \alpha_4 AAP_2 + \alpha_5 \Delta CEPC + u \quad (1)$$

Here,

- $\Delta AGOL$  – first differences of the quantity of the general indicator of productivity in agriculture by years;
- $AAT$  – average annual temperature level;
- $AAT_2$  – indicator of the level of average annual temperature in square expression;
- $AAP$  – average annual amount of precipitation;
- $AAP_2$  – average annual amount of precipitation in square expression;
- $\Delta CEPC$  – first differences of per capita carbon emission quantities by years;
- $\alpha_0$  – free limit
- $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$  – regression coefficient of free variables;
- $u$  – error margin

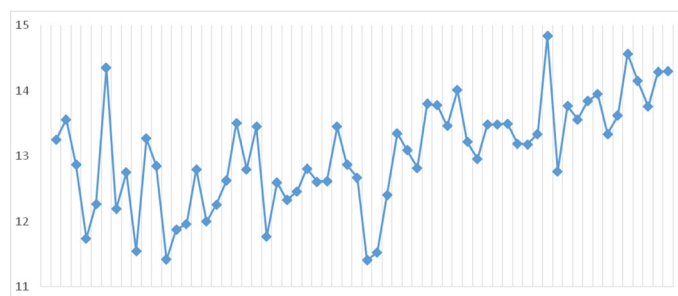
## Results and Discussion

### Dynamics of Annual Average Climate Indicators

Over the long term, the dynamics of average climate indicators in Azerbaijan changed. In the period under consideration, average annual temperature increase was the general trend. This process actually began to manifest itself in the 1990s, or rather in the second half of the 1990s, and accelerated in the 2000s, especially in the second decade of the current century (Fig. 4).

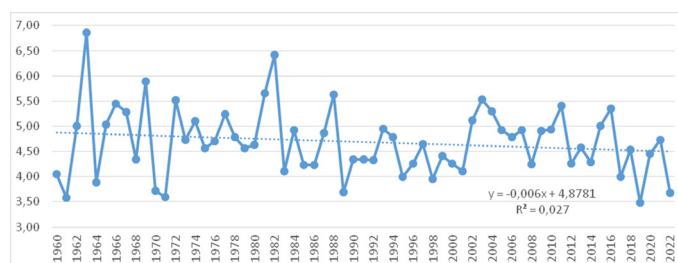
The average annual temperature has been rising at an increasing rate recently. Average annual temperature was 12.59 °C in 1961-80, 12.76 °C in 1981-2000, 13.76 °C in 2001-2020, and 14 °C in 2015-2022.

In contrast to temperature, there is almost no definite change trending in the average annual amount of precipitation for the same period (Fig. 5).



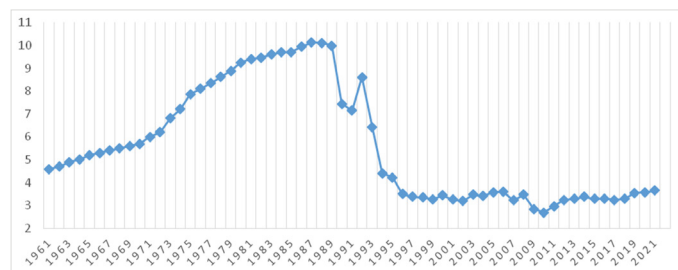
**Figure 4.** Average annual temperature in Azerbaijan, 1961-2021 (°C) (Soures: Appendix data)

There is no consistency to the changes over the years in the variation of the average annual precipitation. At the same time, the number of years considered drought years, in which the amount of precipitation was 100 mm lower than the average level (473 mm for the period under consideration), or 50 mm lower (considered a low-rainfall year) is different in individual periods. In this regard, the increase in the number of drought and low-rainfall years in 2017-2022, when relatively high temperatures also occurred, is noticeable. At the same time, the general synchronicity in the variation of the amount of precipitation and the temperature level is not observed in the review of the entire period.



**Figure 5.** Average annual precipitation (100 mm) in Azerbaijan, 1961-2021 (Soures: Appendix data)

During the period under consideration, drastic changes occurred in the amount of carbon emissions per person in Azerbaijan. In the middle of that period, the 1990s, due to the change in the economic system, there was a transformative decline, and deindustrialization took place. According to official statistical data, in 1990-2000, the volume of industrial production decreased by three times in physical terms, and the consumption of the main types of energy products was reduced by 1.5-3.0 times. Carbon emissions per person decreased sharply (Fig. 6).



**Figure 6.** Carbon emissions per capita in Azerbaijan, 1961-2021 (tons). (Soures: Appendix data)

With renewed industrialization, the volume of carbon emissions began to rise, beginning in the second decade of the 2000s. In 2021, average annual carbon emissions per person was 3.7 tons. This is 2.6-2.7 times lower than the corresponding indicator for the 1970s.

Thus the longterm trend in the carbon emission level is fundamentally different from the trends for the average annual temperature level and amount of precipitation. An exception is that there is some consistency in the dynamics of temperature and carbon emission levels over the last decade.

Thus, graphs of the relevant trends do not allow us to express unequivocal opinions about the direction and nature of the relationship between climate indicators in Azerbaijan during the period under study. There is a need to conduct econometric analysis of the relationships between the variables in the relevant series; such an analysis must consider the stationarity of the variables under consideration.

## Econometric Analyses

### Analysis of Mutual Effects between Average Annual Climate Indicators

In order to find mutual relationships between climate indicators, an analysis of the mutual effects of average annual temperature and precipitation, as well as the change in the first differences of carbon emissions per capita, was carried out using linear regression models for pairs. The corresponding results are given in the table below (Table 3).

The regression analysis shows that the adequacy indicators of the model reflecting the effect of the average annual temperature on the amount of precipitation met the necessary requirements, and the regression coefficient received a statistically significant value. According to the analysis, an increase in the average annual temperature by one degree leads to a decrease in the average annual amount of precipitation by 22 mm. In other words, the changes in the atmospheric temperature act as a factor in the opposite direction and as a perceptible impact on the amount of precipitation. According to another model, a 100 mm increase in the average annual amount of precipitation causes a 0.3 degree decrease in average annual temperature. The literature also states that observed changes in regional temperature and precipitation can be physically related to each other. The negative correlation in

this case is connected by the fact that dry conditions promote less cooling due to more sunlight and evaporation, while wet summers favor cooler air (IPCC, 2012). Another study focused on regions of Nigeria shows that the average temperature of the air decreases in proportion to the increase of precipitation, demonstrating a negative correlation between these indicators (Aweda & Samson, 2022).

Thus, the result of the regression analysis confirms that the recent incidence of higher average temperatures has a real effect on the decrease in the average annual amount of precipitation. Such a situation in itself could not cause a change in the corresponding trend in the average annual amount of precipitation. However, the risk of a greater number of droughts and low-rainfall years rises with the relative strengthening of increases in the average temperature level.

Adequacy indicators of the models that reflect the effect on the average annual indicators of temperature and precipitation of the first differences in the per capita carbon emissions do not meet the necessary requirements and the regression coefficient in both models is not statistically significant. Such a situation can be explained by the effect of the industrialization-deindustrialization-re-industrialization cycle in Azerbaijan's economy during the period under study. At the same time, as it is made clear from the comparison of the corresponding curves from the first and third figures, there was a correspondence in the second decade of the 2000s – the period when reindustrialization was occurring in the country. In other words, there is a certain synchronicity in recent times between the increase in the levels of carbon emissions and average annual temperatures.

### Analysis of Relationships between Climate Indicators and Changes in Agricultural Productivity

The parameters and results of adequacy tests for the model (1) of the relationship between climate indicators and changes in agricultural productivity based on the relevant data for 1961-2021 are given in Table 4.

The model is reliable according to the *F*-statistics criterion. Each of the regression coefficients for the climate variables is statistically significant. The values of the tests of autocorrelation and homeostatic tests on the residuals of the model correspond to the necessary adequacy requirements.

**Table 3.** The regression analysis for the interaction of climate factors

Independent variable/ dependent variable in the model	Number of observation	<i>F</i> -statistic	Parametrs of regression coefficient of independent variable			Durbin-Watson Coefficient
			Coeffisient	<i>t</i> -statistic	<i>P</i> -value	
AAP/ AAT	61	4.416033	-21.9955	-2.10144	0.039883	1.963743
AAT/ AAP	61	4.416033	-0.00317	-2.10144	0.039883	1.046975
Δ CEPC/ AAT	61	0.002275	-0.01025	0.962115	-0.44003	1.087716
Δ CEPC/ AAP	61	0.55813	13.31236	0.747081	0.457982	2.074578

Source: Author's calculations performed using the STATA 15 program based on application data

**Table 4.** Parameters of the model

Indicators	Quantity	<i>t</i> -statistic	<i>P</i> -value
<i>R</i> -multiple	0.549666		
<i>F</i> -statistic	4.762307		
Significance <i>F</i>	0.001096		
$\alpha_0$	-2000.38	-2.59221	0.012191
$\alpha_1$	251.9352	2.174622	0.03398
$\alpha_2$	-9.33307	-2.09377	0.040903
$\alpha_3$	1.250701	2.491487	0.015766
$\alpha_4$	-0.0012	-2.3682	0.021417
$\alpha_5$	23.46736	3.247781	0.001985
DW-statistic	1.655791		
d-statistic $d_i/d_u$	1.283/1.604		
The actual value of the $\chi^2$	-12.9657*		
Criterion for the Breusch-Pagan test	12.59159		

Significant at  $P < 0.05$

Considering that the level of average annual temperatures and the average annual amount of precipitation are each represented by two independent variables in the model, in order to make the necessary evaluations the average regression coefficient for those indicators must first be calculated. Since the variable dependent on the free variables is expressed by a second-order polynomial, the average regression coefficient for the model is calculated as the sum of the product of the regression coefficient of those variables and the regression coefficient in the square expression for the specified level of the variable. (For the calculation of the average regression coefficient for the case in question, see Arkhipova, 2015).

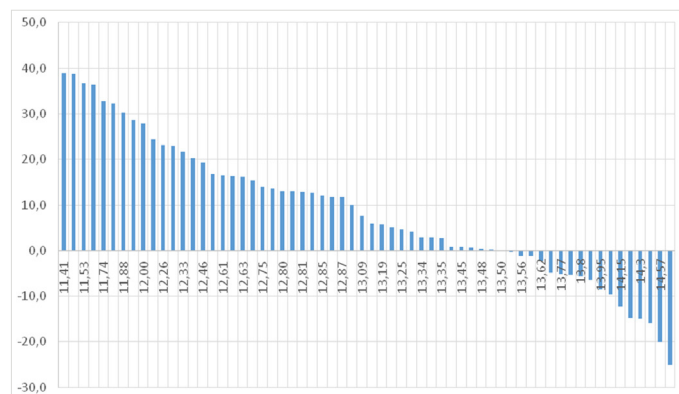
Proceeding from the relevant indicators in the model, the average regression coefficient is calculated as  $(2 * \alpha_2 * AAT + \alpha_1)$  for average temperatures and  $(2 * \alpha_4 * AAP + \alpha_3)$  for average precipitation.

Those indicators are actually "point" quantities for the corresponding mean regression coefficients. These indicators show for how many units (AZN) the physical volume of agricultural products changes per ha of agricultural land, if the amount of temperature or precipitation given at that point changes by one unit (one °C or one mm, respectively).

Based on the average regression coefficients of the model and taking into account the above, the effect of the average annual indicators of temperature and precipitation on the general indicator of productivity in agriculture is evaluated.

According to the data in Figure 7, the values of the average regression coefficient at all levels of temperature equal to or less than 13.51 °C are positive. That is, in every case, every one

°C higher or lower than the average temperature leads to a corresponding change in the physical volume of agricultural product per hectare of land. Thus, an average temperature one degree higher than 13 °C, i.e., 14 °C, corresponds to an increase in the average productivity indicator by 7.6 AZN with comparative prices, and one degree C lower, i.e., 12 °C, corresponds to a decrease of the same amount. In other words, in all cases at the stated level, changes in temperature and the level of productivity due to its effect are in the same direction.



**Figure 7.** Variation of regression coefficients according to average annual temperature levels (Source: Author's calculations based on the parameters of the model)

At the same time, the values of the regression coefficients corresponding to average temperatures of 13.51 °C and higher are negative. If the average annual temperature is one degree higher than this indicator, a change in temperature and the ensuing change in the level of productivity take the opposite direction. High values of the temperature indicator correspond to deteriorating dynamics of productivity indicators and vice versa.

Thus we can say that the threshold effect manifests itself in the influence of average temperature indicators on the change in the general productivity level in agriculture.

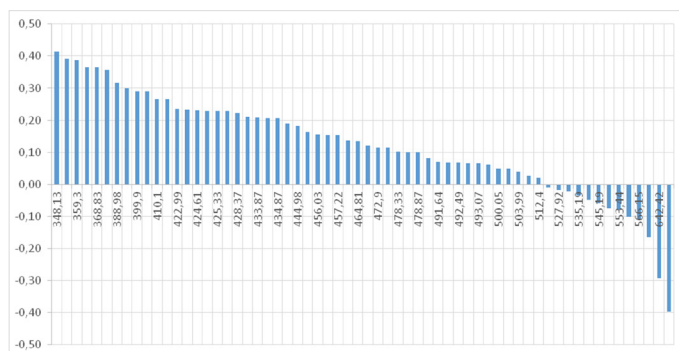
The average level of annual atmospheric temperature in Azerbaijan, up to 14.52 °C, has a positive effect on the growth of productivity in agriculture. The next higher level of temperatures begins to have a weakening effect on productivity growth. After that level, the increase in total productivity diminishes. The magnitude of shrinkage is significant starting at 14.6 °C. (In Azerbaijan, the highest average temperature in recent times was 14.84 °C in 2010. In that year, compared to the previous year, the physical volume of product per ha of agricultural land decreased by 2.4%, and the total volume of agricultural production decreased by 2.2%). According to calculations carried out using the relevant parameters of the model, approximately half of the decline in agricultural production was due to the influence of the temperature factor.

It is also clear from the figure that the reduction in productivity accelerates as the temperature increases. According to the model, a higher level of 0.9 °C in average temperatures means the cessation of the increase of general productivity in agriculture, a level higher than 1.1 °C means a quantitatively significant reduction in productivity growth, and a level higher than 1.9 °C can become a factor in the decline in productivity in relation to the average for the years 2002-2021. (Note that the temperature indicators fit into

the framework of the World Bank's forecast for climate changes in Azerbaijan). Thus, average temperatures in Azerbaijan are predicted to increase in 2040-2059 according to RTC 2.6 by 1.30 °C, according to RTC 4.5 by 1.70, according to RTC 6.0 by 1.60, according to RTC 8.6 by 2.30 °C. (World Bank and ADB, 2021).

Temperatures in Azerbaijan are projected to rise at a faster rate than the global average; under the highest emissions pathway, the projection yields a potential warming of 4.7 °C above the 1986–2005 baseline by the 2090s (RCP8.5) (World Bank, 2023).

According to the model, the threshold effect is also manifested in the effect of the average amount of precipitation on productivity in agricultural production (Fig. 8).



**Figure 8.** Changing the regression coefficient according to the average annual amount of precipitation (Source: Author's calculations based on the parameters of the model)

The regression coefficient of the indicator of the average annual amount of precipitation takes a positive value up to the level of 525 mm. Average regression coefficients corresponding to higher than indicated amounts of the average annual amount of precipitation receive a negative sign. That is, in that case, the change in the values of the mentioned indicators was in the opposite direction.

From the calculations made on the basis of the relevant regression coefficients, it is clear that the higher average annual amount of precipitation, starting from 625 mm, has a perceptible negative effect on the growth of the total productivity in agriculture. Too much precipitation has a negative effect on the vegetation by creating extreme humidity. In 1963, when the highest amount of rainfall was observed in Azerbaijan (in that year, the average annual amount of precipitation was 686 mm, which is almost 1.5 times more than the average for the period under study.), the productivity of all crops including grain growing, cotton growing, tobacco growing and horticulture was decreased. In that year, the physical volume of the total product of agrarian production decreased by 16.3%. The volume of production in the field of crop production was reduced by 27.6%, and in the field of animal husbandry (due to the creation of favourable conditions in fodder), it increased by 7.4%. (CSO, 1965 was calculated based on the data.)

At the same time, according to the results of calculations based on average regression coefficients, if the amount of precipitation is 50 mm less than the average indicator for the studied period (low rainfall), the scale of the increase in total productivity in agriculture will be sharply reduced, and if it is less than 100 mm,

that is, drought conditions, it will cause a decline in the level of that indicator.

Another important point that attracts attention in the data of figures six and seven is the formation of an obvious trend in the magnitude of the change of the regression coefficient in proportion to the change in the average temperature and the average annual amount of precipitation. At the same time, the tendency on the sides of the critical limit border shows dependence in different directions on the change of climate indicators. This shows that the magnitude of the effect of temperature or precipitation on productivity before the critical limit tends to decrease in proportion to the increase in its quantity, and after the critical limit, it tends to increase.

According to the model, the relationship between the increase in the quantity of carbon emissions per person and the increase in the level of overall productivity in agriculture is positive. (According to the model, an increase of 0.1 ton of carbon emissions per person is accompanied by an increase of 2.3 AZN in the physical volume of production per ha of agricultural land). It is clear that the productivity effects caused by changes in carbon emissions are affected first by changes in temperatures. Thus we can say that the relationship shown in the model for carbon emissions is due to the fact that the increase in temperatures in the period under study favourably affected productivity in most years. The literature (Nesirov, 2021), states the fact that the increase in the amount of CO<sub>2</sub> in the atmosphere causes some plants to produce more as a result of taking in more carbon.

## Conclusions

Given a condition of global climate change, studies using longitudinal data are important for investigating the impact of climate characteristics on the general results of agricultural production. It is appropriate to consider how climatic factors (temperature, precipitation, carbon emissions) affect agricultural production as a result of their joint interaction and to consider these within the framework of a single model.

The econometric analysis of longterm data revealed a threshold effect concerning the impact of average annual temperature changes on agricultural productivity.

The rise of average annual temperatures up to a certain level, as part of global climate change, has a positive effect on the dynamics of the overall indicator of agricultural productivity, and after the critical limit in this area is exceeded, the temperature level acts as a factor constraining productivity growth. Thus it is possible to say that the rise in average temperatures since the 1960s, for which we have the relevant data in Azerbaijan, has acted as a positive growth factor in the physical volume of production per hectare. The effect of the change in the level of average annual temperatures on the overall indicator of productivity in the agrarian sector can be explained in particular by its positive effect on the productivity of heat-loving plants, which have a special place in the agriculture of the country. At the same time, it can be explained by factors like the prolonging of the cultivation period in mountainous areas and the expansion of production, including the cultivation of more profitable plants and the creation of conditions for expanding the cultivation of certain plants.

At the same time, since the 2000s, the positive effect of this factor on overall agricultural productivity has weakened significantly, given the relatively higher levels of average annual temperatures, and in some years (2010, 2018), the high temperatures have even acted as a factor constraining productivity growth. It should be noted that continuing the rate of increase of average annual temperatures that has been evident in recent times will lead to passing their critical level, producing an adverse effect on the change of agricultural productivity, and in case the process continues, the result may be a decrease in the level of productivity and the volume of production in agriculture in general.

Econometric analyses carried out using a single model also show the existence of a threshold effect in the amount of precipitation on the change in overall agricultural productivity. In years when the average annual amount of precipitation is very large, extremely humid conditions become a factor hindering the growth of productivity in the agricultural sector. At the same time, it should be noted that in Azerbaijan, an average annual amount of precipitation that negatively affects increase in productivity is found in very few cases, and such a situation is considered an anomalous weather condition. Judging by the longterm trend in the amount of precipitation, it is possible to say that such a condition will remain a rare event in the future. However, the importance of consistently implementing strategies aimed at mitigating the effects of drought and low rainfall, which have a strong negative impact on the overall results of agricultural production, is increasing.

It should also be considered that the increase in average temperatures due to global climate change will increase the number of years when limited rainfall will have a strong negative impact on productivity in Azerbaijan. Although an increase in average temperatures cannot by itself cause the formation of a trend in the overall dynamics of the average annual amount of precipitation, a serious negative effect, i.e., water shortage in the country's agriculture, will be intensified. Drought adversely affects the dynamics of production in both irrigated and paddy-growing zones.

Considering the negative effect of higher temperatures on productivity increases, in the coming years the need to intensify activities that will prevent the increase of carbon emissions is clear. In this regard, the consistent and full implementation of the *National Priorities* (2021) can play an important role, especially the achievement of the main goal of this document—a clean environment and "green economic growth." As the host country for COP29, Azerbaijan is paying more attention to green development, which gives confidence that results of the work done in this field will offer promise for the future.

### Directions for Future Research

This study explores the threshold effect on the impact of average annual climate indicators and is researched only in relation to the general indicator of agricultural productivity. However, future research could delve deeper into examining the threshold effect on the productivity of individual agricultural products, both at the national level and across various regions.

Moreover, analyzing the impact of monthly and daily climate indicators within this framework presents an intriguing avenue for further research. Expanding the scope of research in these directions will necessitate employing advanced analytical methods tailored to ensure the accuracy of findings in each specific context.

In this regard, adopting methodological approaches that account for the complexity of threshold relationships is crucial. For instance, Hansen's threshold regression model (Hansen, 2000) offers a robust framework for addressing the dynamic nature of threshold indicators in complex relationships, making it a promising tool for future studies.

This research primarily focused on the smooth transitional changes method, which is not designed to capture abrupt changes. However, the increasing importance of climate-related issues driven by climate change highlights the necessity for further investigation. Future studies could consider employing Hansen's threshold regression or piecewise regression approaches to more effectively analyze abrupt changes.

### CRedit Authorship Contribution Statement

**Hamza Khalilov:** Supervised the work, analyzed the data and drafted the manuscript. **Firdovsi Fikratzade:** Conceptualization, contributed to the editing of the manuscript and co-supervised this work. **Ramil Huseyn:** Drafted the manuscript, analyzed the data and collected the information.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix

**Appendix 1.** Primary data used in the study (period of the Soviet Socialist Republic of Azerbaijan)

	Physical (real) volume of agricultural output at 2005 prices, million AZN <sup>1</sup> (AGO) (CSO, 1965; SSC, 2024)	Agricultural lands, thsd. ha <sup>2</sup> (AGL) (World Bank, 2024a)	The physical volume of agricultural products in relation to 1 ha of AGLarea, AZN (AGOL)	Annual average temperature, °C <sup>3</sup> (AAT) (World Bank, 2024a)	Annual average number of precipitation, mm (AAP) (World Bank, 2024a; Ritchie & Roser, 2023)	Carbon emission per capita, tonnes (CEPC) (World Bank, 2024b; Worldometer, 2024)
1960	793.8	4079	194.6	12.68	405.22	4.66
1961	634.8	4088	155.3	13.25	357.58	4.66
1962	760.6	4102	185.4	13.56	500.05	4.76
1963	649	4128.9	157.2	12.87	686.11	4.96
1964	712	4130.5	172.4	11.74	388.98	5.06
1965	818.8	4145.7	197.5	12.27	503.99	5.26
1966	834.8	4131.1	202.1	14.35	545.19	5.36
1967	891.1	4228.6	210.7	12.19	527.92	5.46
1968	941.4	4221.1	223.0	12.75	434.37	5.56
1969	881.3	4228.2	208.4	11.55	589.57	5.66
1970	1037.8	4252.8	244.0	13.27	372.1	5.76
1971	1031.865	4254.2	242.6	12.85	359.3	6.06
1972	1067.981	4265.6	250.4	11.42	552.2	6.40
1973	1217.498	4268.4	285.2	11.88	472.9	6.82
1974	1424.472	4267.4	333.8	11.96	509.9	7.22
1975	1381.738	4275.6	323.2	12.80	456.9	7.88
1976	1566.891	4274.1	366.6	12.00	470.4	8.10
1977	1776.855	4274.5	415.7	12.26	524.5	8.35
1978	1924.334	4275.5	450.1	12.63	478.6	8.62
1979	2070.583	4277.4	484.1	13.51	456.0	8.88
1980	2319.053	4282	541.6	12.80	463.4	9.25
1981	2488.344	4289.6	580.1	13.45	566.2	9.40
1982	2533.134	4306.4	588.2	11.77	642.4	9.47
1983	2555.932	4318	591.9	12.60	410.1	9.61
1984	2757.851	4319.6	638.5	12.33	492.9	9.71
1985	2688.904	4327	621.4	12.46	423.0	9.72
1986	2635.126	4338.3	607.4	12.81	423.6	9.95
1987	2608.775	4351	599.6	12.61	486.4	10.14
1988	2527.903	4364.3	579.2	12.62	563.2	10.12
1989	2267.529	4372	518.6	13.45	368.8	9.99
1990	2265.262	4382.9	516.8	12.87	434.9	7.45

**Appendix 2.** Primary data used in the study (The period of independent Azerbaijan)

	Physical (real) volume of agricultural output at 2005 prices, million AZN (AGO) (SSC, 2024)	Agricultural lands, thsd. ha <sup>2</sup> (AGL) (World Bank, 2024a)	The physical volume of agricultural products in relation to 1 ha of AGLarea, AZN (AGOL)	Annual average temperature, °C <sup>3</sup> (AAT) (World Bank, 2024a)	Annual average number of precipitation, mm <sup>4</sup> (AAP) (World Bank, 2024a; Ritchie & Roser, 2023)	Carbon emission per capita, tons (CEPC) (World Bank, 2024b; Worldometer, 2024)
1991	2272.057	4448.7	510.7	12.67	433.9	7.16
1992	1731.308	4446.2	389.4	11.41	433.2	6.61
1993	1462.955	4456.7	328.3	11.53	495.0	6.41
1994	1275.697	4486	284.4	12.41	478.9	4.41
1995	1186.398	4489.1	264.3	13.35	400.2	4.23
1996	1221.99	4526.2	270.0	13.09	425.3	3.50
1997	1147.449	4588.7	250.1	12.82	464.8	3.38
1998	1077.454	4682.1	230.1	13.80	395.7	3.35
1999	1153.953	4692.4	245.9	13.78	441.4	3.27
2000	1293.582	4740.4	272.9	13.46	425.4	3.44
2001	1437.169	4745.6	302.8	14.01	410.6	3.25
2002	1596.695	4744.9	336.5	13.22	512.4	3.20
2003	1686.11	4754.6	354.6	12.96	553.4	3.47
2004	1763.671	4754.9	370.9	13.48	529.9	3.41
2005	1844.8	4758.6	387.7	13.49	492.5	3.58
2006	1861.403	4756	391.4	13.50	478.3	3.59
2007	1935.859	4756.5	407.0	13.19	492.3	3.22
2008	2053.947	4756.7	431.8	13.18	424.6	3.47
2009	2125.835	4757.2	446.9	13.34	491.6	2.85
2010	2079.067	4766.8	436.2	14.84	493.1	2.68
2011	2199.652	4768.7	461.3	12.77	541.2	2.97
2012	2344.829	4768.3	491.8	13.77	425.3	3.24
2013	2459.726	4769.8	515.7	13.56	457.2	3.29
2014	2395.773	4769.7	502.3	13.84	428.4	3.38
2015	2553.894	4769.8	535.4	13.95	500.1	3.29
2016	2620.295	4772.9	549.0	13.34	535.2	3.30
2017	2730.348	4777.5	571.5	13.62	399.9	3.24
2018	2855.944	4779.5	597.5	14.57	453.0	3.29
2019	3061.572	4779.7	640.5	14.15	348.1	3.54
2020	3122.803	4780.1	653.3	13.76	445.0	3.50
2021	3228.979	4780.6	675.4	14.29	473.1	3.70

<sup>1</sup> As a result of the inclusion of the number of agricultural workers and the used land areas which are available in the model as free variables together or separately, the regression coefficients for those variables do not receive statistically reliable values. At the same time, in those cases, the relevant parameters for all three climate indicators receive values corresponding to the necessary reliability requirements. This strengthens confidence in the stability of the dependencies that are revealed within the framework of the model we are looking at.